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## Autonomous and rapid deployment of a compact taut-wire mooring

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### ABSTRACT

The deployment time of a taut-wire mooring is reduced to the time any transportation/hoisting device needs to put a payload at the sea surface. This is a matter of minutes rather than hours needed for deployment of long deep-ocean moorings in the regular way. It is achieved by extending the basic function of mooring parts to temporarily form a Launcher for Oceanographic Equipment and Instruments (LOEI). Full preparation of the mooring is done onshore where the instruments are prepared and programmed, and spooled onto the top-buoy together with the line. At sea, no other gear is required than a device that is able to lift a load of, say, 2000 kg, even for long deep-ocean moorings. The compact mooring method realizes considerable budget savings through deployments from non-research vessels and airborne transportation-deployment. Limitations lay in size and weight of the oceanographic instruments. We present a test-design shaped as a barbell and loaded with 940 m line and 3 current meters. Unfurling speed was maximally  $2.3 \text{ m s}^{-1}$  and the descent speed amounted  $1.2 \text{ m s}^{-1}$  until landing on the seabed. These speeds are comparable to those acquired during a conventional free-falling mooring deployment.

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### 1. Introduction

All taut-wire oceanographic instrumented moorings have in common that they are equipped with an anchor weight for fixation to the seabed, a given length of cable and floatation to keep them upright. The oceanographic instruments are attached to the cable at predefined distances from each other. The full amount of buoyancy can be arranged on top of the mooring or smaller floatation devices can be distributed over the mooring line (Heinmiller, 1976; Tupper et al., 2000; Frye et al., 2002). The former has the advantage of easy recovery as the cable remains suspended in the deep and only a pick-up line and one buoyancy element surface, thereby avoiding entanglement. The advantage of the distributed floatation is that when the line incidentally breaks and a certain amount of buoyancy is lost at least part of the mooring remains recoverable.

Deployment methods vary; they may be done from the stern or from the side, putting the anchor weight first or last. They all have in common that special gear, like winches and A-frame, are needed; gear that is common on research vessels but not necessarily on commercial vessels. The majority of the oceanographic taut-wire moorings are relatively simple in their constituent components.

Deployments of these moorings are not very demanding either, when weather and sea conditions are not considered.

A simple mooring design allows the user to prepare and compact the complete mooring far ahead of time of deployment. This broadens the variety of vessels to be chosen from, saves deployment time and gains weather independency. Knox and Sessions (1979) describe the deployment of a compacted mooring from small vessels. Basically, the “buoy first, anchor last”-deployment procedure is followed with the difference that the mooring line is not spooled out from a winch of a research vessel but manually, from a small automobile wheel used as a reel.

The compact mooring method presented here describes the multifunctional use of parts of the mooring to form a Launcher for Oceanographic Equipment and Instruments (LOEI). This launcher allows the deployment of moorings from almost any transportation device. To do so, the functionality of the top buoy is extended. Onshore the function is a winch drum and storage device for cable and instruments; when deployed it changes to a floating winch that unfurls the entire mooring. Finally, it acts as a basic floatation device that stretches the mooring line. The anchor weight is connected to the rest of the mooring onshore. It too has more functions than only being an anchor. First, it acts as the transportation platform for the compacted mooring. Second, it becomes a power device to unroll the mooring from the drum. Third, it acts as the anchor weight to secure the mooring to the seabed. Three deployments have been performed at sea using a first realistic test-mooring and the results are presented below.

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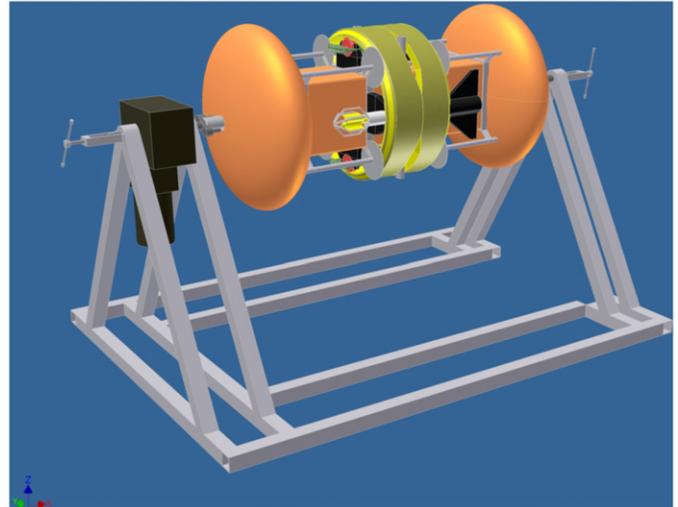
**2. Method and materials**

The launcher concept is tested with a floatation device/winch drum made of two syntactic foam elliptical floats and three square syntactic foam blocks. The two floats are set on their sides with the square blocks in between. They are connected to each other by a central aluminum tube and a welded aluminum construction over the square blocks (Fig. 1). In this test-example, the net underwater buoyancy of the launcher construction is 2000 N. Its shape resembles a barbell with a middle section divided into three parts. The central part is used as a reel to store the mooring line. Clamps with tie-wraps are distributed over the surface to temporarily hold the instruments until the moment of deployment. The tie-wraps snap-off at a load of 30 kg as tested using a weigh-beam.

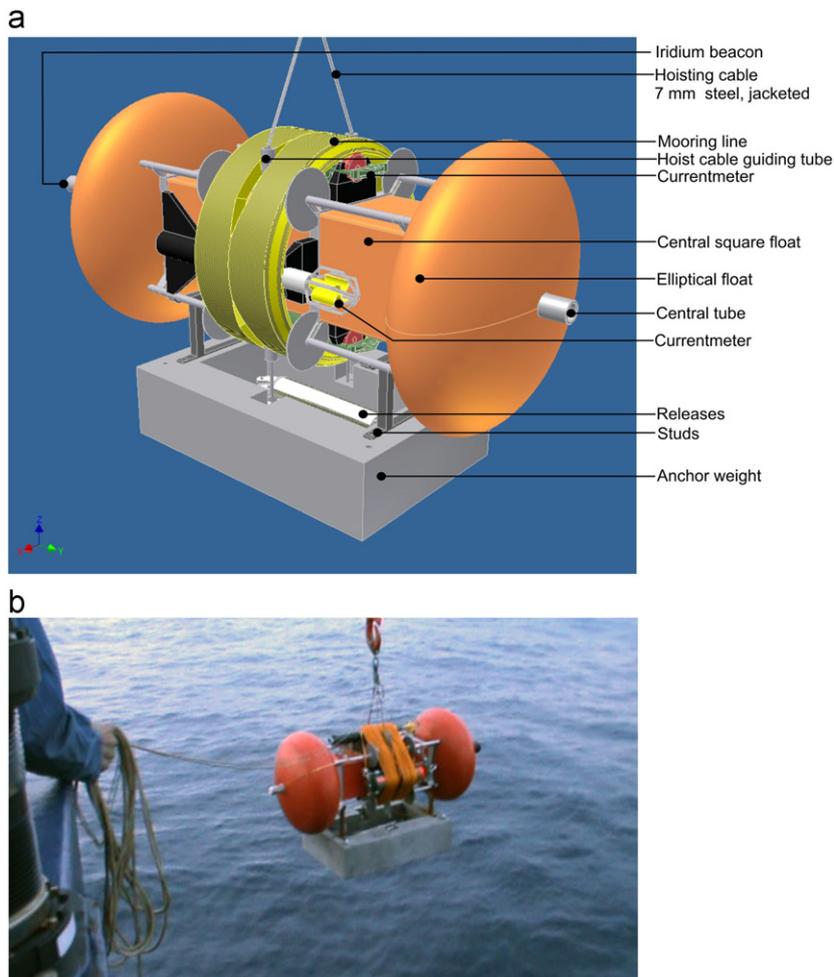
Depending on the size of the instruments they can be stored either in radial or axial direction where they cover the central part of the barbell. The axially directed instruments get covered by the mooring line during the spooling process, which also secures the instruments to their mountings.

The central axial tube allows the complete device to be mounted in a rotary spooling traction. This forward and backward electrically driven rotary traction ('rotator') is constructed from square aluminum tubing and is capable of rotating loads up to 3000 kg and with a maximum diameter of 2.2 m (Fig. 2). This allows easy spooling under controlled and comfortable circumstances onshore. During the present test-deployments, the rotator has also been used on board a ship.

A 940 m long, 0.004 m diameter, 12 strands braided synthetic Dyneema® mooring line was used with home-made sewed end-terminations. These terminations replace more common eye-splices that are elaborate to make. To protect the line from abrasion a nylon bushing was inserted in the sewed end-termination. The line



**Fig. 2.** Launcher in rotator.



**Fig. 1.** (a) Launcher for Oceanographic Equipment and Instruments (LOEI) (b) video-still just prior to test-deployment.

is neutrally buoyant, seawater resistant, light, flexible and strong. The maximum breaking load (MBL) is 1200 kg according to the supplier (Lankhorst Ropes). This has been confirmed in several tests including the sewed-on end-terminations. The latter are proven not to induce any reduction of the line's breaking strength. Prior to deployment, line tension was estimated not to exceed 400 kg ( $=\text{MBL}/3$ ) for expected currents ( $0.1 \text{ m s}^{-1}$ ) using a dynamic mooring design program (Dewey, UVic, Canada). This allows use of a thin cable to minimize mooring drag.

As test-oceanographic instruments, three different types of current meters have been used. A mechanical Valeport BFM-308 (underwater weight of 9.5 kg) current meter was mounted at 183 m, an acoustic Aanderaa RCM\_11 (18 kg) at 506 m and an acoustic Nortek Aquadopp (3 kg) at 831 m below the top buoy (Fig. 3). The acoustic current meters are attached to the line via separate swivels. The swiveled Valeport was not programmed; it was only used to check whether the impellor could resist the forces exerted by the relatively fast rotation through the water during deployment-unfurling. The RCM\_11 was programmed with a sampling period of 300 s. The Aquadopp collected 25 measurements at a rate of 1 Hz, every 60 s. Its temperature and pressure sensor data are used to understand the unfurling and deployment process. These data and the current data are used for a first evaluation of a short-term taut-wire Dyneema-line mooring. A Xeostech Sable Iridium satellite beacon was fixed in the central tube to form the eventual top of the mooring.

The concrete anchor weight of 460 kg in air was designed to store two iXSea AR861B2S acoustic releases inside its central cavity. This cavity also prevents the anchor weight from excessive

swaying while sinking. The weight's surface dimensions equal a Euro pallet of  $0.8 \times 1.2 \text{ m}$ . Concrete is used for three reasons:

- The cast can be easily adapted to the smallest details required.
- Once the cast is made, reproduction of anchor weights becomes routine.
- The cost for any following anchor weight decreases.

Concrete has the disadvantage of a relatively small 1:2.5 density ratio compared to seawater. However, its potentials for easy adaptation of shape and dimensions of the cast and the assembling in a compact mooring outweigh this disadvantage.

To carry the entire compacted mooring a simple steel construction frame-stud was bolted on top of the weight. The total dimensions of the compact mooring LOEI are thus  $0.8 \times 1.2 \times 1.4 \text{ m}$ .

### 3. Preparing the mooring on the launcher

The loading of the launcher with line and instruments is done on the rotator. Line is fed to it from a storage reel; the first few meters are set aside in a corner of the launcher awaiting the end of the spooling procedure and removal of the launcher from the traction device.

When the adjustable traction is switched on, the barbell rotates at a speed set so that the person who is guiding the process feels comfortable enough to bring the line adequately onto the launcher. Tension was kept low ( $< 2 \text{ kg}$ ) during rotary traction. The process does not require extreme precision. Some attention should be given to equal distribution of line over the surface. Depending on the diameter of the launcher, the rotating speed, the number of instruments to be connected and the length of the line, the process will take nearly the same amount of time as is needed for the spooling of a mooring cable to a ship's winch or the time needed for a regular deployment straight into the water from a ship. In this first and experimental set-up we needed two hours to load the barbell with 940 m Dyneema<sup>®</sup> line and 3 instruments. We estimate that this time will be reduced to about one hour when the process becomes routine.

After completion of the loading process the launcher is taken from the rotator. The earlier stored beginning of the line is the end-termination that has to be fixed to the buoy. In order to have the buoy floating upright after unfurling the line is fed from the bottom side through the central tubing to the top where it is fixed. Finally, the Iridium beacon is mounted onto the buoy. For easy recovery purposes a small pick-up buoy and 15 m floating line could be stored and secured on the launcher; to be released by the unfurling line at the last revolution of the launcher.

The launcher is placed on the frame-studs on top of the anchor weight. Two short 7 mm steel cables, already fixed in the middle on both sides of the weight are fed through two guiding tubes through the launcher into a release hook. These cables make anchor weight and launcher inseparable and stabilize the launcher onto the weight during hoisting actions and launching. Hoisting of the complete mooring is thus done exclusively on the anchor weight.

### 4. Deployment of the launcher

Deployment of the LOEI is a short procedure. The combined anchor weight plus compacted mooring is put over the side or stern with a crane capable of lifting this moderate weight of 800 kg (test mooring). As soon as the launcher touches the sea surface the cable-connected release hook is opened. Instead of a crane plus a release hook other deploying devices may be used

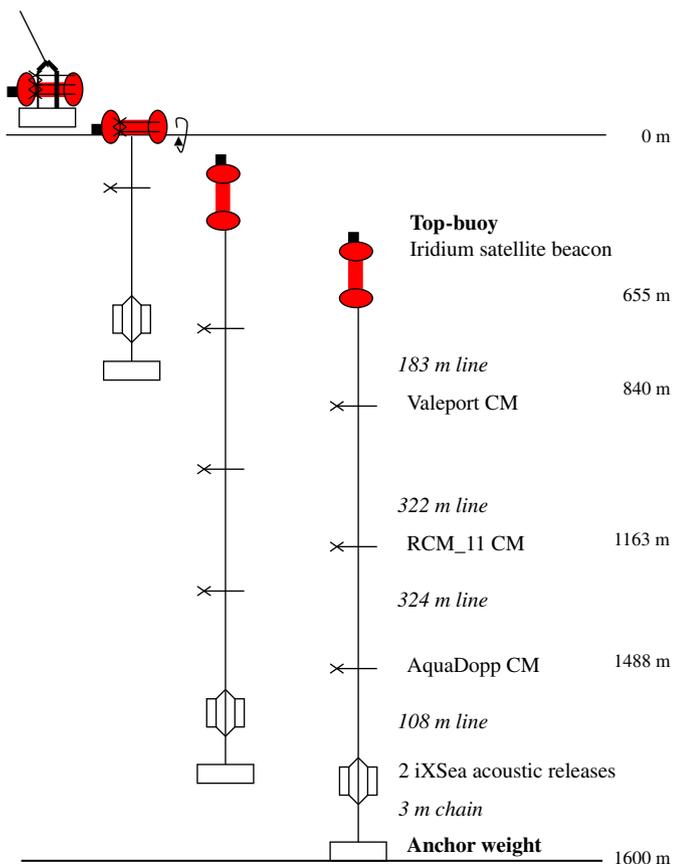


Fig. 3. Cartoon showing the deployment, release and unfurling from the surface and landing on the seabed.

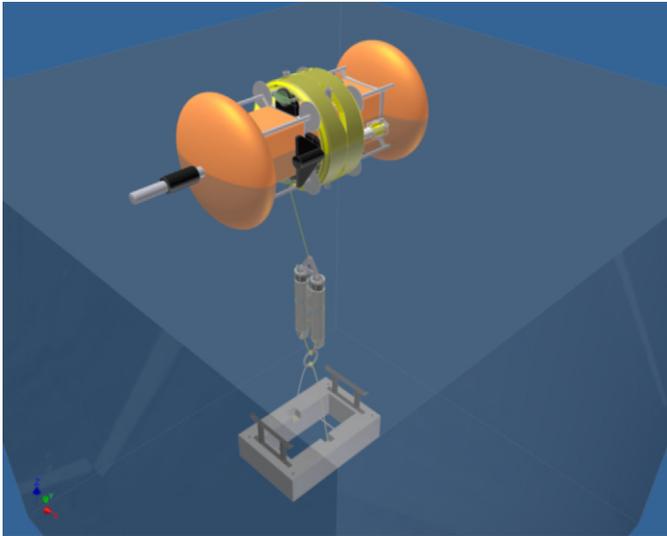


Fig. 4. Artist impression of unfurling.

such as a slid-launcher. The falling weight pulls both short steel hoisting cables through the tubing thereby freeing the launcher that immediately starts unfurling (Fig. 4).

#### 4.1. Recovery of the mooring line

Recovery of the LOEI-mooring is identical to any conventional mooring recovery. During this test we spooled the mooring line to a ship's winch. During detachment of instruments we held the opened line after placing a holding-loop in a hook attached to an A-frame. Alternatively, one could hold the loop by a tholepin attached to the board-railing. To facilitate a near-immediate re-launch of the mooring upon recovery, the entire mooring can be spooled directly from sea on the launcher. In that case, the rotator with launcher is placed behind a capstan that pulls the mooring out of the water. With a set of replacement instruments the mooring can be re-deployed immediately after the line is completely recovered. It implicates the re-use of the mooring line which is possible for synthetic fiber ones.

### 5. Results and discussion of first field test

We deployed the above test mooring with nearly 1000 m line and 3 current meters three times from R/V *Meteor* at different sites in the Ionian Sea varying between  $H=1600$  and 2200 m water depth. The purpose of this first set of three deployments was to investigate and to establish a few crucial parameters. They were;

- Is the rolling launcher stable enough to allow undisturbed unfurling?  
During all three deployments the launcher showed a remarkable stability. Due to the slightly uneven distribution of mooring line and instruments over the surface of the launcher the resistance in the water was also slightly unevenly distributed and therefore it turned slowly in small circles of approximately 10 m radius around its vertical axis while unfurling at the surface. During the third deployment the wind speed was  $10 \text{ m s}^{-1}$  with a 1.5 m swell. The launcher rode the top of the waves with ease. No influence to the unfurling process could be noticed visually.
- What is the unfurling speed of the mooring from the launcher?

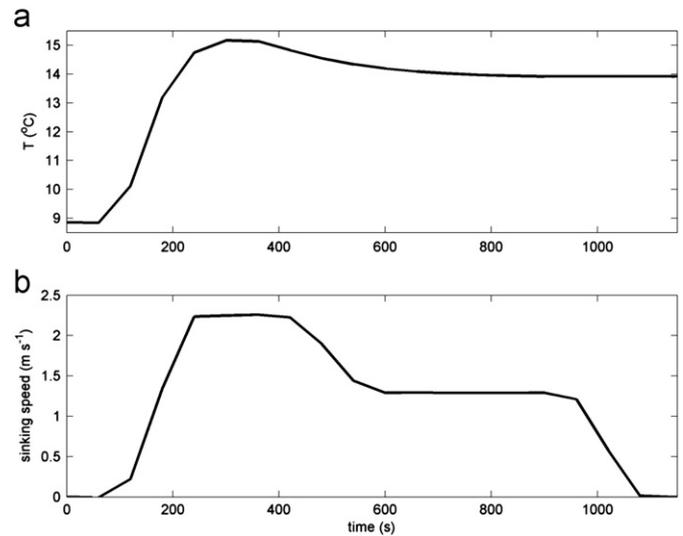


Fig. 5. Duration of the deployment procedure and unfurling speed as inferred from temperature (a) and pressure (b) sensors, mounted 110 m above the anchor weight. The original 1 Hz data from the third test-deployment are averaged over 60 s.

Data from temperature and pressure sensors (Fig. 5a,b) show that the unfurling process took less than 600 s and that the maximum speed computed from the pressure sensor data was  $2.25 \text{ m s}^{-1}$ . The anchor weight landed on the seabed after 950 s ( $H=1600 \text{ m}$ ) with an end speed of  $1.2 \text{ m s}^{-1}$ . All measured values are considered normal for a nearly free falling taut-wire mooring, during towing and initial sinking ( $2\text{--}2.5 \text{ m s}^{-1}$ ) and final landing ( $1\text{--}1.5 \text{ m s}^{-1}$ ).

- Are there any unforeseen technical complications related to the unfurling?  
There are no technical complications detected that could jeopardize the process. During the first launch the mooring line hooked behind a bolt on the frame of the RCM\_11 thus blocking the unfurling process as could be observed visually. The launcher went down as launcher instead of as top buoy. After recovery, the problem was fixed by putting half a plastic protective tube around the bolts. No damage to line or other instruments could be observed by this blocking.
- Does the unfurling affect the performance of the instrumentation?  
No damage was done to the instruments during unfurling. The impeller of the mechanical Valeport current meter remained intact. Battery connections, potentially a weak spot in self-contained instrumentation, were not affected in any instrument. Once the mooring line was in place, the instruments registered currents and other parameters normally.
- Are any changes to the concept needed?  
The concept as such proved successful and was performed without conceptual problems at sea, but ameliorations are suggested for future LOEIs. Both the winding speed of the cable on the launcher and the unfurling will benefit from a larger diameter. The barbell shape may be changed to a cylinder by mounting the four rods on the corners to the outer diameter of the two elliptical vertically standing buoys. The effective circumference will increase from 1.8 m to 3.3 m. This allows for a change in orientation of instruments from axial to radial. In that case all instruments lie in the direction of rotation and they may be stored separately from the mooring line in the compartments to the left and right of the central part. If more storage space is required for the mooring line the middle part can be enlarged as well.

## 6. Technical limitations

This very first launcher was initially designed to store and launch 4 current meters of moderate size like an Aanderaa RCM\_11 or Nortek Aquadopp and 2000 m mooring line. The mooring was kept relatively simple and short so that all attention was focused on the observations of the spooling and unfurling process. As discussed above the outer diameter of this launcher could easily be enlarged and widened thereby providing more space for line and instruments.

Limitations lay neither in the length of the line nor in the number of instruments but primarily in the dimension of the instruments. Rolling a large sediment trap on the top buoy would be hardly possible, but adaptations can be made to accommodate instruments as large as 75 kHz acoustic Doppler current profilers. No problems are expected to construct a LOEI for long deep-ocean moorings using 4000–5000 m line, anchor weights of around 1000 kg, 800 kg buoyancy and some 10 instruments. The present rotator, capable of holding a 2.2 m diameter and 3000 kg weighing launcher, would be more than sufficient to spool such up-scaled LOEI that still fits into a standard 6 m long sea-container for easy transportation.

## 7. Budgetary consequences for autonomous deployments

On a non-commercial basis the one time investments in new gear to arrange a compact taut wire mooring remain moderate. The rotator was built in the NIOZ workshop for 9485 US\$, which includes the cost for 100 h of labor. Assuming a lifetime of 100 mooring-spoolings for the rotator, the investment costs are 95 US\$ per mooring.

Adaptations made on this first experimental top-buoy were out-sourced for 5200 US\$. More than half of the labor hours were devoted to trial and error during design and construction. Since the present LOEI is a prototype the cost for the production of the next generation will be much lower due to substantial labor savings and adapted design of new buoys. The costs for the one-time investment of the rotator are to be spread over the lifespan of buoys in addition to the number of mooring-spoolings.

A conventional ocean-mooring deployment takes 2 h, with at least 2 specialist-technicians involved. Deploying a LOEI takes 10 min by the ship's crew. This difference in deployment-time expressed in terms of research vessel-costs already outweighs top-buoy modification costs, even the expensive first trial one given above. Most profit is undoubtedly made by chartering non-

research vessels, which are much (generally several times) cheaper and easier to find.

## 8. Conclusion

The process of loading a mooring on a launcher is not determined to be faster than a regular deployment from a vessel when line and instruments are lead directly into the sea. However, the place where the work is done changes from a fully equipped and expensive research vessel to the comfort of a workshop ashore. The benefits gained derive from the fact that all preparations, including instrument programming, can be done under controlled circumstances with inexpensive gear. If necessary, for example when container transport to remote research areas requires a long time, spooling and instrument-programming can be done in the harbor of departure, or on board. Transportation and deployment of the compact moorings are simplified and can be done with any vessel or even airborne, saving research time and budget. During deployment, the risk of losing or damaging a mooring is lower because the forces on the line remain constant and low. Bad weather and sea conditions are less important.

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